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CONCEPTUAL DESIGN OF A MAP INTERACTIVE SYSTEM (MIS) FOR MILITARY AIRCRAFT COCKPITS

A THESIS

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

MASTER OF ARTS

By

CRAIG J. WENZ

Norman, Oklahoma

1994

CONCEPTUAL DESIGN OF A MAP INTERACTIVE SYSTEM (MIS) FOR MILITARY AIRCRAFT COCKPITS

A THESIS
APPROVED FOR THE DEPARTMENT OF GEOGRAPHY

BY

T.H. Lee Williams

Robert A. Rundstrom

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PREFACE

This thesis on map interactive systems arose from my personal and professional background and interests. I am a military pilot and a graduate of the United States Air Force Academy. My undergraduate major was in geography. While attending the Academy, I made 22 flights in a sail plane. I attained ten hours of flying time in a single engine trainer, the T-41.

I attended undergraduate pilot training at Vance Air Force Base from July 1992 until July 1993. During pilot training, I flew 81.5 hours in the Cessna T-37B Tweet. This aircraft is the primary twin-engine jet trainer for the U.S. Air Force. I also flew 107.3 hours in the Northrop T-38 Talon. This aircraft is the advanced jet trainer.

Directly following my graduation from pilot training, I attended graduate school. During this time, my interests have been in the area of cartography. I have extensive experience with military maps since attending the Academy in 1988. I used aeronautical charts on a daily basis throughout pilot training. The map interative system developed here is based on literature reviews, questionnaire results from a cross-section of military pilots, and my own observations and experience with military aeronautical charts.

CHAPTER I

INTRODUCTION

As the complexity and sophistication of military aviation operations rise, the effective interaction and display of map information becomes increasingly important. The purpose of this thesis is to provide a background and directions for those developing new technology in the area of air navigation and to propose a conceptual design of a Map Interactive System (MIS) for military aircraft cockpits.

The MIS is an air navigation system that will provide pilots with map displays both on the ground and in the cockpit. Map displays will allow a pilot to view the surrounding environment along the desired route of travel using multiple perspectives. The system will be designed so a pilot may interact with the display, and send and receive vital information while in flight. It will be an amalgamation of current and future technology.

The primary purpose of the MIS is to verify a pilot's location and lead him/her to the mission target. Additionally, the MIS displays threat information and provides the pilot with a fast and accurate means of

communicating with multiple agencies, and will have several advantages. Pilots will be able to warn other pilots of present threats. Airborne commanders will be able to direct members of the mission by means other than voice communication. This will decrease the chances of enemy interception. Pilots will be able to warn ground bases of threats, and in turn, ground bases will be able to warn airborne pilots. A MIS may reduce the number of reconnaissance aircraft required to perform such duties as updating current threats, and damage assessment. It could certainly benefit those involved in search and rescue. Knowing where the enemy is in relation to a friendly soldier can be life saving. This rapid communication can prevent the unnecessary loss of life by reducing the fog and confusion involved in a conflict.

Since most pilots are already heavily tasked, a MIS must have a few guidelines. First and foremost, this system must not interfere with the primary duties of the pilot, those being basic aircraft control and mission objective. Secondly, the system must be easy to learn and simple to use. These two guidelines must be central to the design of such a system.

Sources Of Information

The conceptual design of the MIS will be based on

a synthesis of literature and an application of knowledge and experience from four areas:

1. The first area involves a review of cartography. The historical preconceptions and purposes of maps will be examined in order to understand future uses, and existing cockpit resource literature will be reviewed.

2. Pilot experience and input is an important consideration when designing any cockpit system. A pilot survey was conducted and the results are used as a source for designing the MIS.

3. Human factors are vital to the creation of a functional display or map for the high information load cockpit environment. This area will be reviewed.

4. The final source of information that will be used to assist the conceptual design is that of personal experience of the author as a military pilot.

These areas will be discussed in the following chapter. Both general and specific recommendations will be given pertaining to the conceptual design of a cockpit MIS.

Assumptions

In order to make this investigation practical and manageable, a few assumptions are necessary. First, it will be assumed that the aircraft in which the MIS is initially installed has a single-seat cockpit. The

reasoning for this assumption is that a system developed for a single pilot will be simple enough for all cockpits. If there is a need to expand the complexity of the MIS for use in multiple-occupancy cockpits, it will be easier to do so than trying to modify a complex system for use in a single-seat cockpit.

Computer technology will play a large role in the success of the MIS. Since the aim of this investigation is to develop a conceptual model for the MIS, it will be assumed that technology and system capabilities will continue to advance at the same rate as is evident today. It is a safe assumption that technology standards (processing speed, data storage and transfer) five or ten years hence will be capable of meeting the MIS requirements described in this investigation.

It will also be assumed that systems that will interact with the MIS will be able to do so within the frameworks of different military agencies. If the MIS can not efficiently relay data between different agencies then the designed system will be inefficient for the desired purposes mentioned above.

CHAPTER II

MAPPING SYSTEMS

This chapter reviews the history, preconceptions, and current trends in cartography and their relationship to a cockpit MIS.

Historical Perspectives

Aircraft cockpit environments present a unique setting for a Map Interactive System. The optimal form of a MIS will be unique to the cockpit environment. Traditional preconceptions about maps may not be appropriate, and current trends in cartography offer a variety of options for the cockpit.

Mankind's quest for adventure through exploration has been fueled by the desire for spatial understanding. Ask yourself, 'what makes the view from a mountain peak so spectacular'? Is it the large open sky? Is it the splendid variety of trees that make up the forest? Is it the town nestled in the valley below? It is not one part of the view, but rather every detail of the view. The view is so brilliant because there is a new perspective. Everything is viewed in its place. From the peak one can see where the town rests in relation to

the forest. There is a greater spatial understanding of the surrounding environment. This spatial understanding is the transparent bond that unites all the subdisciplines of geography, cartography being one of them.

There are many subdivisions within cartography just as there are many subdivisions within geography. There is a theoretical side of cartography which seeks to maintain structure. There is a technical side which aims to improve the mechanics of how maps are made. Yet there is a unifying fabric in this subdiscipline of geography.

Geography and cartography are concerned with the spatial relations among phenomena. In the past, cartography has been considered a communication science; however, new views have developed. Today, scholars recognize that cartography is more than just geographic illustration. It also involves geographic thinking (MacEachren and Ganter 1990).

Spatial information is illustrated and communicated in many different ways. It can be transmitted using pictures, words, and smells. And, though it can be received through any one of our many senses, spatial information is most commonly exchanged using representations known as maps. Maps have been made in many forms in the past. Some were made using stone,

others were and continue to be made using paper and pen.

What Is A Map?

The traditional idea of a map is the first preconception that must be dealt with. Not so long ago maps were defined in the following way: "...[A] graphic representation of spatial relationships and spatial forms is what we call a map" (Robinson et al., 1984:3). If cartographers believe that maps are limited to graphic form then there is little room for change in the field. Not all maps are tangible. Maps can be created in the mind. Maps can be created on computer screens. And soon maps may be created using holograms.

Maps have also been thought of as objective representations of reality. This belief has been refuted by those who argue that there is no optimal map. It is abstraction not realism that gives maps their unique power (DiBiase et al., 1992). MacEachren and Ganter (1990:64) expand on this point:

> Maps and other visual representations are valuable to science, not because of their realism, but because they are abstractions. The abstraction process, if successful, helps to distinguish pattern from noise.

Although a cartographer may strive for realism, this can not be completely achieved because cartography is an inherently abstract art.

Until new ways to represent spatial relations are

developed, maps can be defined using broad classifications. Kimerling (1989:698) classified maps into four groups based on Moellering's concept of real and virtual maps as follows:

1. Real maps, which are directly viewable as cartographic images that have a permanent tangible reality.
2. Directly viewable virtual maps-type 1, which lack permanent tangibility, such as CRT map images.
3. Virtual maps-type 2, which are not viewable as a cartographic image, but have permanent tangible reality, such as gazetteers.
4. Virtual maps-type 3, which are neither viewable nor have permanent tangible reality, such as disk files or mental maps.

Hard-copy maps are only one aspect of modern cartography. Our reliance on hard-copy maps has caused delays in the advancement in cartography. As helpful as they have been they only represent one moment in time. This is another preconception associated with maps. Maps do not have to be limited to a single moment in time. When maps are chained to a single moment, many harmful assumptions are made. The user often assumes that the spatial relations on the map are constant. The map is thought to represent the present when in fact it only represents the moment at which the data was collected for its construction.

Another popular misconception is that a map is an accurate representation of reality. Many cartographers strive for this quality, but since the world is

infinitely detailed, it is impossible to accurately represent reality. Since a map must have finite detail, it is the responsibility of the creator to decide which data to include and which to leave out. This leads to a bias towards the creator's perception of the world. The cartographer's perception of the world determines how it is generalized. Generalizations by different individuals are generally inconsistent. "It is fairly safe to say that no two generalizations done by humans are identical" (Robinson 1984:248). Some cartographers argue that generalizations are an art-form and some argue that they are important information losses. Think of the mountain view described earlier. A painting, a picture, and a mental image of the mountain view might all be different yet they supposedly represent the same picture of reality. Each interpretation is effective in its own way to a variety of users.

There are a great variety of map users. Take for instance a hard-copy topographic map. It could be used for many different purposes by many different users. Campers could use it for hiking, military members might use it for mock battles. It could be used for road, house, or dam construction. Because the number of cartographers is few and the amount of data included in each map can vary, a cartographer can not possibly include all data required to meet the demands of every

user. The cartographers dictate the data that is depicted with each map. In order to prevent great discrepancies between cartographers' styles, standards are suggested. It was not until the 1950's, when Robinson wrote The Look Of Maps, that standards became widely accepted in modern cartography. With modern technology, standards have once again become an active area of interest. This will be discussed in greater detail later.

The preconceptions discussed here are important in the context that map concepts and map designs are not limited to the ideas of the past. Maps and mapping systems are no longer limited to pen and paper technology. Currently in the aircraft cockpit environment hard-copy paper maps are used, although advancements in technology will soon allow soft-copy or digital maps to be used instead. The cockpit environment is quite different from traditional map user environments, and various map display options available today can be considered in the conceptual design of the optimal cockpit environment.

Cartography And Related Fields And Technologies

Another common preconception surrounding cartography is that it is independent of other subdisciplines of geography and even of other

disciplines. However, it is becoming more readily apparent that with the advancement of technology, cartography is heavily dependent upon other subdisciplines and other disciplines. Cartography is becoming increasingly more involved with geographic information systems (GIS). Many GIS are being managed and advanced by cartographers. According to Aronoff (1993:1), "a GIS is designed for the collection, storage, and analysis of objects and phenomena where geographic location is an important characteristic or critical to the analysis". One of the problems with a GIS is that users are able to easily produce information that can be misleading. For example, a user may create a large scale, hard-copy map depicting land use from data acquired at a small scale resolution. It is important that basic cartographic skills be automated into GIS packages in order to prevent data from being misrepresented. Muller (1991:11) presents this argument: "New models will have to incorporate the cartographic naivety of the user, as well as the motivations for making the map in the first place". This can be accomplished through cooperation between cartographers and those involved in computer science. Together they can develop programs which will automate basic cartographic skills.

There are benefits to using a GIS. In many cases,

users are better able to explore multiple options with more relevant data, and make better, accurate analyses. Furthermore, users are able to make factual and strong recommendations, and are able to reach decisions and implement recommendations quickly.

Another subdiscipline of geography which is concerned with handling and analyzing geographic data is remote sensing. Remote sensing and associated image analysis technology provides access to spatial information that was once difficult to gain and collect. Throughout the world, remotely sensed data of spatial relations are being analyzed using GIS. Most GIS are being managed on a global scale. Remote sensing greatly enhances the capabilities of GIS to update map information on a regular basis. There have also been successful applications of change detection by integrating cartographic and remote sensing data.

Another recent technological advancement that will benefit both cartography, GIS, and remote sensing is the global positioning system (GPS). The GPS offers considerable intrinsic value for navigational, tracking, and surveying technologies. It also greatly increases the utility of a GIS database. Abler (1993:135) goes so far as to say, "GPS may well be the key technology needed to foster the integration of remote sensing, GIS, and cartography into a single information system".

All of the fields and technology mentioned above can and will advance the field of cartography and will play an important role in developing a worthwhile and practical air navigation system.

Characteristics Of Future Maps

Cartographers currently rely largely upon techniques which were developed long ago. Very minor changes have occurred over the decades. Hard-copy maps that were drafted by hand and revised using aerial photography still dominate over all other types of maps. Hard-copy maps are the dominant map type from which military pilots must navigate. The maps are often out of date and inaccurate to some extent. Pilots are often displeased with the maps they must work with on a daily basis.

In the near future this will not be the case. Maps will be designed and updated using digital technology and computers, and much of the map making process will be automated. Cartographers, however, will still be responsible for certain generalizations and boundary discrepancies. The soft-copy map will be the focus of the user and hard-copy maps will only be by-products of the system.

Soft-Copy Revolution

Traditional cartography provides a platform for an advancement in technology-based cartography. Muller (1991:11) predicts customized maps will dominate the future.

> The traditional division of labor between map makers and map users is disappearing. This new development results in the production of customized maps which are topically much more specific and flexible than the maps produced by mapping agencies.

Many see cartography becoming integrated with other subdisciplines such as Abler (1993) suggested. Cartography, remote sensing, and GIS will be combined to form an information science. This information science will be concerned with issues such as data collection and database management.

With the constant advancement of computers and other related technologies, data are being collected at a faster rate than ever expected. Today, many sources of data exist. Analysts can not possibly sort through all of the data fast enough. Finding sources with relevant data is a difficult task in itself. Database management systems are being developed to help sort and maintain data. Providing access to these databases will be a role of the new cartography/GIS analyst.

The Defense Mapping Agency (DMA) has recently re-evaluated its purpose and undertaken several mission adjustments. The DMA has shifted its emphasis from

paper map products to Geospatial Data Management. The DMA is no longer product-oriented but rather information-oriented. If the customer has the hardware, software, and training, then he/she becomes the producer of hard-copy products using databases maintained and provided by DMA.

This shift in cartography is referred to as the "soft-copy" revolution. This revolution has led to the development of ephemeral maps and new ways to view maps. Both static and dynamic maps can now be viewed on computer monitors. In the future these maps will become more intricate and detailed and will be supported by databases loaded with information which the user will be able to access easily. One recent development in cartography which may provide a tool to utilize these databases is animated cartography.

Animated Cartography

Researchers are seldom interested in a static view of the world, but until recently, static maps were the only visualization tools provided. Researchers need to see change over time. Animation allows cartographers to incorporate time directly into visualization tools. According to Campbell and Egbert (1990:29):

> Animation is based on the well-known principle that the eye-brain mechanism retains, for a fleeting instant, images of objects it has seen after the objects have been removed. Therefore, if the eye is shown a series of static views, or 'frames,' of objects at a rapid rate (typically 30 frames per second), with the objects changing positions only slightly from frame to frame, the illusion of fluid life-like motion is created in the brain.

There are three kinds of change which can be visualized when using dynamic maps. The first involves spatial change. The most common example of this is what is known as a fly-by. The view-point of the observer changes with time. The second kind is chronological change. This occurs when maps are sequenced in a time-series. The third kind is attribute change. This involves the change in position of an object in attribute space such as when smoothing filters are used to mask pattern noise (DiBiase et al., 1992). Attribute change is also referred to as re-expression. An example of this type of change is the reordering of maps displaying anti-aircraft activity. Rather than ordering the maps according to the time of the activity, they could be ordered in increasing intensity. This way, heavy activity can be associated with geographic locations.

The most common use of animated cartography has been in flight simulation. Animated terrains change as a viewer's inputs to flight controls change. Animation

has also been used to examine geologic, hydrologic, atmospheric, and oceanographic processes. The pace of development of animated cartography is uncertain only because of its slow development in the past. The advanced technology of computers may provide a rapid increase in research and applications in this area.

For the purposes of the Map Interactive System (MIS), animated scenes may help pilots to visualize the environment they will encounter before flying a mission. Animated scenes, however, are not always beneficial during all phases of a mission. There will be periods when dynamic maps will distract pilots. For example, when a pilot is en route to a target, animation will not be appropriate because a pilot will be preoccupied with other, more important tasks and the animation may be distracting.

Animation will be useful to pilots when they prepare for a mission and after they return from a mission.

Car Navigation Systems

Car navigation systems are currently developing at a rapid pace. Many of the basic ideas behind car navigation systems can be used to design air navigation systems. Moving-map displays allow the user to view another perspective of the outside environment as he/she progresses in a vehicle. Databases are hooked to GPS

locational data allowing the user to pinpoint his/her location. Vehicle navigation systems (VNS) can also suggest alternate routes of travel if a road is blocked or congested. Air navigation systems can have these same options.

VNSs are an example of applied computer cartography and may someday include scenes developed from animated cartography. Claussen and Mark (1991) emphasize the revolutionary role cartography is playing in developing vehicle navigation systems.

> Automated vehicle navigation systems have come into existence primarily due to the progress in digital cartography, and thus VNSs represent an important area for advanced research in cartography, even if some systems do not include graphic map output (161).

VNS research topics include the need to review essential characteristics of digital maps for navigation and related functions, a topologically encoded and seamless database, and fast data retrieval. Although many similarities exist across all vehicle navigation systems, there are also many unique situations specific to air, land, and sea navigation.

Later in this thesis, the phases of an air navigation system will be discussed. Research for vehicle navigation systems form a useful reference when developing a map interaction system. One example is the moving-map display.

Cognitive Psychology-Cartography

Cognitive psychology is sometimes overlooked by those who are rapidly advancing the "soft-copy" revolution. It is however, a very important aspect which must be considered when designing a new cartographic system with new types of maps. If cognitive psychology is ignored, an air navigation system may not be as effective as it could, and should be. Research in cognitive psychology can help decrease the interaction time required between the pilot and the mapping system.

Effective perception and communication of spatial phenomena hinge on the human cognition process. This links some cartographic research to cognitive psychology. Experiments in cognitive psychology strongly indicate that images are functional representations of human thought. Maps and mental images are spatial representations, and the interaction between the external map and the internal image is important to the communication process.

Mental images are intellectually processed and generalized representations, much like maps. Both mental images and maps are products of spatial thinking. Both depend on the process of arranging objects in space, identifying patterns, and creating order. The concept of internal images raises questions in

cartography that concern both map construction and map reading. Research about internal images may play an important role in answering these cartographic questions.

Research has been conducted regarding map reading. In these studies, researchers looked for responses to cartographic designs. Wood (1993:151) states:

> An important finding of the mainly experiment-driven studies was the overpowering influence of the map reader's previous knowledge, education, experience and motivation.

Text, or place name, was found to induce processing to recognize or place an area on a map. Following this, small, personal, and familiar places become important (Dobson, 1979). After recognition, users tend to look for the purpose of a map. The limits of information density on maps has not yet been determined.

Cognitive research in cartography can be problematic. The underlying problem related to cognitive research involves the fact that cartographers and psychologists have different objectives. The cartographer's aim is to meet the needs of the map reader, and advance map design. The psychologist tries to understand more general ideas such as those involving the process of communication and individual human differences. This difference leads cartographers to other problems such as misuse of psychological theory and weakness in experimentation.

In terms of the MIS and cockpit displays, there will be a need for clear presentation of map data. The research of cognitive psychology can be more narrowly focussed because there will be a narrow range of users who are highly trained and educated. Researchers can focus specifically on a pilot's ability to commit important features of a map to long term memory. They can also focus on exactly which features are important for long term memory. Maps which emphasize different features may be more effective during different phases of a flight mission.

Summary

Cartographic systems are changing from a hard-copy to soft-copy digital database format. Military aviation mapping will follow the trend as the DMA moves from a hard-copy to a soft-copy database. Cartography itself is evolving to include dynamic as well as static display of data. The MIS will rely heavily on the expansion of cartography to include GIS, GPS, and remote sensing techniques. Developments in VNS moving-map displays provide a useful starting model for dynamic moving map cockpit displays.

Chapter III

PILOT/NAVIGATOR QUESTIONNAIRE

In order to evaluate the status and problems of current maps and map use in military aviation, ten pilots and navigators were surveyed. The pilots were selected through the author's personal experience with members from a variety of military bases. Their flying experience ranged from two years to ten years of flying, with a wide range of experience in fighter, bomber, transportation, trainer, helicopter, and refueling aircraft.

The pilots and navigators were asked what they think of current navigational maps, and what they would like to see changed. The questionnaire is given in Table 3.1.

Table 3.1 Pilot/Navigator Questionnaire.

1. Which aircraft do you have experience with?
2. What is your experience with navigation maps? (e.g., paper maps, electronic displays, other)
3. What knowledge do you have of electronic displays? (e.g., the name of the display system and a brief description)
4. What are the problems with the current navigation maps?
5. Suggestions for improving navigational maps.

Results

1. Aircraft Experience

Ten aircraft types were represented, shown in Table 3.2.

Table 3.2 Aircraft Type.

General Dynamics FB-111A Aardvark (Fighter-Bomber)	Boeing B-52G/H Stratofortress (Bomber)
Bell UH-1 Huey (Helecopter)	Sikorsky UH-60 Black Hawk (Helecopter)
Lockheed C-5A Galaxy (Cargo/Transportation)	Boeing KC-135 Stratotanker (Refueling)
Cessna T-37B Tweet (Trainer)	Northrop T-38 Talon (Trainer)
Northrop AT-38 (Trainer)	T-1 (Trainer)

2. Navigation Maps

All pilots still carry paper maps for basic navigation purposes. The paper maps are still used as the primary means for navigational reference. Half of the aircraft types listed above have some type of electronic display to support navigation.

3. Electronic Displays

Except for the newest trainer, the T-1, trainer

aircraft do not have any electronic displays for either preflight planning or in the aircraft itself. The UH-1 does not have any type of electronic display either.

The KC-135 and C-5A have an Inertial Navigation System (INS). This system plots way-points along the aircraft's planned route of travel. The INS is linked directly to the automatic piloting system. It is very basic and uses lines and points for display symbols on a cockpit CRT display (if available).

The FB-111A is primarily a low-level bomber and therefore flies low-level routes the majority of the time. Paper maps and radar are used to navigate along these routes. As part of pre-flight planning, the pilots individually construct a book of paper maps, much like an atlas, which covers the entire route of travel. The Weapons System Officer (WSO) looks at a radar screen and compares the radar shadows to the paper maps in flight. The WSO is trained to assist the pilot in navigation and deliver the weapons to the target. The WSO is seated beside the pilot in an FB-111A and behind the pilot in a B-52G/H.

Information was not available concerning what is used in a B-52G/H because of security reasons. The pilots and navigators did not say if they share the low-level maps constructed. The FB-111A pilots did say that the low-level map book is very basic in terms of

construction. Information and routes are drawn on paper maps by hand with colored markers.

The UH-60 has an electronic device. However paper maps are the source of data for the device. The pilots who use the device say there are many problems with it and would like something else to use for navigation. Again, limited information concerning the particular aspects of the device is available.

4. Problems

The pilots pointed out many problems with the current navigation maps. First and foremost, all of the pilots said that the maps are out-of-date and often inaccurate. The maps often depict buildings at the wrong location or ones that do not exist. Since maps are often ten years old or older, they must be updated before every flight by the individual pilot. The pilot must consult chart update manuals containing information such as new towers along the flight path or new areas that must be avoided. Cities and towns are frequently represented by the wrong shape or size and often are not represented at all.

Another problem pointed out by seven of the pilots is that current maps only present one perspective. Three-dimensional perspective views are not available. Although there are different map scales available, maps

usually lack the detail pilots want. The paper maps are usually big, bulky, and difficult to fold to the desired size. This leads to cutting of the maps and wasting paper. If several maps are needed, pilots must cut and paste maps. In the case of the FB-111A pilots, books must be made. These pilots say it is easy to lose one's place among the pages of the map books. With the increased use of GPS technology, latitude and longitude are becoming as important as other navigational references. Yet, latitude and longitude lines are difficult to see on present paper maps because they are not the primary way to identify one's position in the air. These lines need greater emphasis.

The keys of current paper maps are difficult to read and a pilot must look at the fine print for symbols which are not always simple to understand. This can be a special problem for new pilots.

5. Suggestions

The most common suggestion among the pilots was to have an electronic system that has up-to-date and accurate information. They also suggested that the display could provide a print-out of only the area of interest. The pilots desired a display with multiple perspectives such as a 3D perspective. Simple symbols and improved legends were also requested by the pilots.

All of the pilots said they would like to have a computer program that computes headings, fuels, and timing for their particular aircraft. This information is currently derived by the pilots based on daily wind conditions and planned altitudes.

Summary

All of the pilots questioned said that most of the maps they use are out of date. They would like to see a system with accurate and up-to-date information. They would also like to have a selection of scales and viewing angles. Low-level maps were said to have insufficient detail. Pilots must cut and paste maps as well as add more information. They would like to have a system where they can define parameters and have information such as: how much fuel should be remaining at a certain point along the route of travel.

Pilots today are flying technologically advanced machines but must guide themselves with basic paper maps that normally contain out-dated information. Pilots must manually update maps with current information posted in separate listings. It is an unnecessary additional workload for the pilot to have to update, and cut and paste maps, with only limited information.

Pilots often play 'guessing games' attempting to match information on a map to the actual objects along

the flight path. It takes several clues before they are able to confirm their position. The time spent playing these guessing games while flying is a waste of a valuable commodity and can cause a pilot to miss targets and increase the potential risk of life.

CHAPTER IV

HUMAN FACTORS

In order to provide optimal usability for the pilot, the design of the MIS will involve aspects of human factors. There are several definitions of human factors. Sanders and McCormick (1987:4) provide a general definition:

> Human factors, then, seeks to change the things people use and the environments in which they use these things to better match the capabilities, limitations, and needs of people.

For the purposes of cartography, mapping, or spatial data systems could be substituted for the word "things".

This idea is similar to that of the "home field advantage". Designers are able to build an environment that gives the home team an advantage. Designers can build an attractive stadium which draws a greater number of supportive fans, or, a stadium which is oriented so that the wind assists the throwers, hitters, or runners. The minor design details can collectively give a home team an advantage since they are oriented around the special abilities of the team. These are just a few examples of how designers can use human factors to build

a comfortable and efficient environment. Human factors considerations can also help designers create a cockpit navigation system which will assist pilots to manage and process information which is presented at a rapid pace.

The Pilot

A discussion of human factors should logically begin with a review of the pilot. It is assumed by non-aviators that pilots have a high level of detailed knowledge and understanding of all the various aspects of aviation. In reality, pilots are taught the basics of many aspects of flying, but rarely do they become experts in all areas. For example, pilots learn the basic layout and operation of several systems of an aircraft. One specific system is the engine system. A pilot learns enough information about the engine system to recognize how the aircraft will respond in flight if one portion fails. The pilot can identify the source of the failure by using pre-determined operation limitations of the engine. This is important for pilots to learn for two reasons. The first reason is that pilots must know how to identify and respond to the failed system. Secondly, it is important so that a pilot can inform the aircraft mechanic of the problem area within the system. However, a pilot usually does not know how to strip down an aircraft engine and

rebuild it. A pilot only needs to know enough about the system to overcome difficulties while in the air. The same is true with a pilot's knowledge of the weather. A pilot is not expected to become a meteorologist in order to fly. Pilots are usually given a two-week course on basic weather patterns and conditions that should be avoided.

So, how much should a pilot be expected to know about an aircraft system? If a pilot were expected to master every aspect and every system involved with flying, it would take many years before a pilot would be prepared to fly. A pilot should be expected to learn how to operate aircraft systems safely and to know the operation limitations of various systems. It is not necessary or even practical for a pilot to understand every aspect of a system.

This basic consideration helps to define the nature of future map information systems for pilots. Hard-copy maps are inflexible in design from the pilot's perspective. Soft-copy maps can be extremely flexible. However, it may be bad for a pilot to have a great amount of flexibility in map design because he/she is not an experienced cartographer and many inaccuracies may be generated that could be detrimental during flight. Therefore the designers of a MIS should provide pilots with a system that is simple to operate, with

specific operation parameters that allow customization, and with display options that are constrained.

The designers should, however, provide a system that does allow pilots the flexibility to communicate a variety of information to others. The effectiveness of the system will be determined by limiting how much a pilot may interact with the MIS to manipulate an image or map. There must be a limit in order for all agencies receiving the information to understand what is being communicated. If the pilot is allowed to personalize a system too much, others will have difficulty interpreting important information.

General Considerations When Working With Maps

With the emphasis being shifted from map production to data management, cartography is becoming more involved with human factors. Cartographers will have to automate the basic principles of cartography, since production will be in the hands of the user who may be miles away. Many concepts from human factors can be helpful when designing a map interaction system or any air navigation system. Researchers must understand and incorporate human factors, in order to create systems that are supportive and efficient.

Interaction: How Much - How Rapid?

When designing a map system for air navigation, there are many human factors to consider. Several of these are the pilot's capability to quickly process the spatial data presented, identifying the technology which will allow the best information transfer, identifying the advantages and disadvantages of a particular system, and the workload of the pilot.

Pilots have a very heavy workload and an MIS should not interfere with a pilot's prioritized duties. The primary job of a pilot is to fly the aircraft in a safe manner. A pilot's second priority is to monitor all systems to ensure he/she can maintain safe flying. The next priority is to accomplish the assigned mission.

Throughout each flight a pilot is continually collecting and processing information by directly or indirectly sensing his/her environment. This is primarily accomplished through sight. A pilot can directly sense the environment by using the "see and avoid" technique. This may occur, for example, when a pilot looks outside of the cockpit to identify and avoid other aircraft. A pilot can indirectly sense the environment by looking at radar signatures of other aircraft on a screen. There are three major factors associated with a pilot's vision. They are acuity, accommodation, and light intensity (Edwards, 1990).

Acuity is the ability to discern details of visual input. Accommodation is when the eye changes shape in order to provide focus. When developing the MIS, these two factors are of less concern since pilots must pass medical examinations each year. The third factor, light intensity, must be considered when designing the MIS because it can directly affect a pilot's performance.

The intensity of light plays a major role in determining the speed with which information from the MIS is processed. For instance, one can read much faster in a well-lighted room as opposed to a very poorly lighted room. The same holds true for displays. A well-lighted display is easier to read than a very dim display.

> The eyes normally move about three or four times a second. These saccadic movements are of great speed; about 90 percent of the time is spent in fixations (Edwards, 1990:10).

A poorly lighted display can cause a pilot to fixate longer on that display than he/she can afford.

The cockpit environment is characterized by a high information load. A large volume of data must be clearly and brightly presented so a pilot can quickly process the data into useful information. The primary purposes of a display are to illustrate and assist the viewer's thinking process. If a display is designed improperly it can be misinterpreted or may even be unreadable. A pilot's perception can be influenced by

the way information is displayed.

Types Of Maps

Map information in a cockpit can be displayed using static or dynamic data, in two or three dimensions. Pilots currently work with two-dimensional (2D) static maps. Flight instructors often use three-dimensional (3D) dynamic models to explain airport patterns and basic maneuvers. These 3D dynamic models usually involve model airplanes mounted on sticks which the flight instructor moves (flies) by hand.

Currently, while flying, a pilot is limited to using 2D static hard-copy (paper) maps. Realistically a pilot would benefit from 2D dynamic maps which move as the aircraft flies across the earth. Before and after flying, 3D static maps could be used to explain techniques for entering certain situations. Three-dimensional dynamic maps, could be used on the ground to prepare a pilot for an actual mission.

Three-dimensional space is a more accurate means of depicting airspace. "The 3D representation is clearly a compatible and natural representation of the airspace..." (Stokes, 1990:28).

Even though 3D representation may be a natural representation of airspace, it is not without its problems. A 3D map image may inhibit a pilot's ability

to make precise readings on a specific dimension. It may be easy to judge the relative location of an object in 3D space, but it is difficult to quickly and accurately pin-point the location of the object (refer to Figure 4.1).

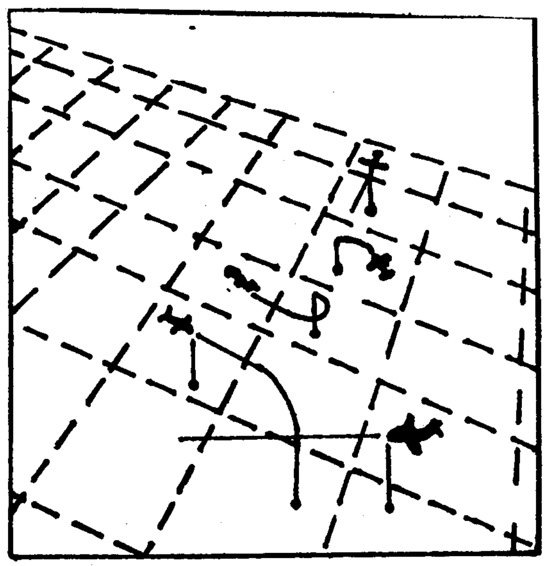

Figure 4.1 3D Image On A Flat Screen.

For instance, in Figure 4.1, it is relatively easy to see where each aircraft is in relation to the others. However, it is difficult to determine their exact

locations over the ground. This problem can be overcome if a three-dimensional MIS is used as a supportive tool in conjunction with two-dimensional views.

Another problem with 3D perspectives is that objects located along the same line of sight may obscure one another. This is analogous to sitting behind a post at a sporting event. Some action will be missed if it occurs in a direct line with the viewer and the post. Again, this problem can be overcome by using 3D maps in conjunction with 2D views.

One solution might involve the viewing azimuth and elevation angle. By choosing a different azimuth and/or angle, a viewer can overcome the problems mentioned above. This solution sounds simple, but it may lead to further problems such as distortion of objects, or slowing of a pilot's processing time due to an inconsistency of frames. Inconsistency of frames will be discussed in the next section.

One conclusion about 3D display maps is that they are "information rich" and therefore may not be appropriate for all phases of flight. Information overload could cause the pilot to become distracted or even disoriented. Therefore 3D dynamic maps should not be used during flight.

Design Criteria For Aspects Of Navigational Displays

The real world is infinitely detailed but a map is limited in detail. The pilot of an aircraft must rely upon a map when in unfamiliar territory. In order to navigate, the pilot must process data from a mapping system, the instrument panel, and the outside world. This is a demanding task. With the advancement of computer technology, this task may be easier to accomplish than before.

Several companies have the technology to develop navigational displays. For instance, Martin Marietta has already developed a low altitude navigation targeting infrared night system (LANTIRN). This system displays the terrain below an aircraft using infrared sensors.

Regardless of the system or the type of sensors being used, each navigation display will have some limitations stemming from human factors. These limitations will depend entirely on the specific system being designed. There are several general limitations worthy of consideration when designing a system such as the MIS.

Consistency Of Frames

One area of concern involving a navigational display is the frame of reference the display will

represent. A navigational display usually shows an element or a set of elements moving in relation to a stable background. Determining which elements move and which are stable, depends on the frame of reference. For instance, a display can show the progress of an aircraft against a stable environment whereas another might show the environment moving around a stable aircraft. Both of the frames of reference have specific advantages and each can be implemented with relative ease. Individual pilots may not have any difficulty adapting to either type of display. A problem arises, however, when a new navigation display system has a frame of reference that is different from the frame of reference on established or traditional instruments. It is difficult for anyone to rapidly reorient between different frames of reference. Frame reorientation can cause a pilot to fixate on instruments and displays longer than he/she should and can lead to errors.

There are two possible solutions to this problem. One is to separate the display from other instruments and make it very distinctive with different colors and attributes. The other is to design a navigation display which uses the principle of consistency of reference frames. If a navigation display is designed using consistent of frames of reference, then the pilot will be able to process information from many instruments, at

a faster rate, and there will be less confusion as to which elements are stable and which are in motion (Stokes, 1990). This principle suggests that a new instrument should hold the same frame of reference as those to which the pilot is already accustomed. Two primary instruments that a pilot is familiar with are the Attitude Director Indicator (ADI) and the Horizontal Situation Indicator (HSI). These two instruments use an inside-out view towards navigation. This frame of reference holds the aircraft stable and the surrounding environment moves around the aircraft. The inside-out frame of reference is therefore the best choice for the MIS.

Color

Another area of concern when developing a navigation display is the display's use of color. Color and pictorial displays may be aesthetically pleasing, and they may be useful, but a few words of caution are needed because the operational implications of color factors have not been well researched.

Depending on the task, there are several potential advantages to using color. First, memory seems to be improved in the short term, and memory decay is slowed when color images are used to display information (Dick, 1970). Christ (1975) reported that color can unify or

cluster information from other fields. This may help decrease the time it takes for an individual to process information. It may also hinder the time it takes if similar information is coded in separate colors.

Other research shows that people respond more rapidly to color coding than to shape coding (Smith and Thomas, 1964). Color can also lead to performance improvements by yielding greater response accuracy (Stollings 1984).

However, one important study by Woodruff (1979) showed that no difference in pilot performance was found for pilots using color simulators versus black and white simulators. This study showed that displaying simulated images in color, as opposed to monochrome, did not make a difference in pilot performance.

Color has been used in cockpits since World War II for engine instruments. Color markings are used to indicate if engines are operating within design limitations. Today, the McDonnell-Douglas F-15E has color on certain instruments as a test-bed for other aircraft.

The use of color in navigational displays should be approached with caution:

> High-frequency spatial information (fine edges and other details) is perceptible in both black-and-white and red-green color channels, but the colors themselves may not be unambiguously distinguishable" (Stokes 1990:75).

In other words, too much color may saturate or overwhelm the viewer by cluttering a dynamic display.

In practice, color-coding features or system parameters is not a major design consideration since the military already has standards in place that insure colors match those of aeronautical charts. However, color discriminability on color CRT's is different from that on paper maps, so research is needed on the readability of traditional aeronautical chart colors when displayed on color CRT cockpit displays.

Clutter

The presentation of too much information can render a display useless. If a navigation display is saturated with too many different types of information, the pilot will have to spend extra time discerning which information is relevant at a particular point in time. Exactly which information is helpful, and which is simply clutter, will depend entirely on the type of navigation display and the current task.

One type of clutter already mentioned is color clutter. Too many colors or a high saturation of colors can hinder the pilot performance. Ways to avoid color clutter are to limit the number of colors used in the display. Another method is to emphasize contrasting colors so the pilot may easily distinguish between

different types of information.

Another way that information can clutter a pilot's thinking process occurs when non-essential information is displayed. Some information, such as outside air temperature, may be completely irrelevant on a navigation display. Some redundant information, such as altitude, which can be acquired from other instruments, may reinforce the pilot's decision-making process and is therefore helpful. Other redundant information, such as the hemisphere in which the aircraft is operating, may produce useless clutter.

Navigation display systems must have a minimal amount of clutter. Systems should assist the pilot in organizing information and should shorten the time the pilot must scan and process that information. A navigation display should be simple and helpful.

Another possible solution that minimizes the amount of clutter in navigation displays is to design a system that allows a pilot to decide which information is relevant. For instance, a pilot may choose to include data which depict all local roads. He/She may decide to leave out certain data which depict all local buildings. Designing an adaptive (or flexible) system such as this could eliminate many clutter problems.

Size Of Display

The last general concern involving navigation displays is the size of the display. Cockpit display space is extremely limited in any aircraft. A 25-inch video screen would be awkward, distracting, and impractical. A display must be small enough to fit among other instruments yet large enough to enable a pilot to discern the information being displayed. Exact display size will depend on the individual installation.

Presenting Relevant Information In A Useful Manner

Computerized navigation systems are a relatively new idea and few standards have been set regarding how they should display information. Individual navigation systems have functions that are different in other systems (manual functions in some systems may be completely automated in others). For instance, some systems may allow the user to choose the scale of the map whereas other systems will have this option fixed. Difficulties arise when information is simplified, excessive, or unorganized. The following sections discuss these difficulties.

Automation

Automation is utilized within cockpits to relieve the pilot of tasks which are time consuming, complex,

costly, or even too dangerous. Automated systems can be designed to be reliable and accurate. Some examples of automated cockpit systems are the autopilot, anticollision systems, and ground proximity warning systems. One important reason for the success of each of these systems is their compatibility with the pilot.

In order for an automated system to be compatible with the pilot, it must be designed to meet the demands and expectations of the pilot. Expectations enable the pilot to process information at a faster rate because he/she can anticipate changes. One example is the symbol of another aircraft used in an anticollision system. If the shape of the aircraft is used to represent the aircraft rather than a square or a dot, the pilot can process information faster. The pilot can recognize the threat and identify in which direction the aircraft is moving almost immediately. When designing a navigation system, symbol utilization and automation are important considerations. If one or the other is not compatible with the pilot, the system could fail. If improper symbology is used in a navigation system that is over-automated, the system may fail and that failure may never be recognized.

A major concern with automated systems is that they may cause a decrease in pilot skills. The pilot may become over-reliant and be reluctant to check or

question the validity of an automated system. Sometimes the opposite can occur. The pilot may not feel comfortable with a system or may not be compatible with the system, and in this case, may choose to ignore the system or not use it at all. In these cases, navigation systems are often ignored because pilots feel they interfere with their flying skills. Oppitek (1973) found that 11 out of 17 pilots turned off their Head-Up Display during critical phases of flight because it interfered with their performance. Head-Up Displays contain dynamic information similar to that contained in 3D dynamic displays. Because of this, during the engagement phase of a mission, the use of 3D dynamic displays should be avoided.

Fully automated systems are not desirable because pilots need to see relevant information to assist them during important decision making moments. If a system was fully automated, it would carry out the actions it was programmed to perform regardless of the consequences and would not be able to respond to unusual circumstances. Pilots are still important because they can override systems during crisis situations.

Information Overload

Since there is an almost overwhelming amount of data displayed in a cockpit, pilots must prioritize and

organize data before it is processed. A pilot accomplishes this using selective attention. "Selective attention requires the monitoring of several channels (or sources) of information to perform a single task" (Sanders and McCormick, 1987:65). When sampling many sources of information, pilots tend to sample sources in which the information is updated very frequently, as opposed to those sources which are updated infrequently. As the number of sources of information increases, a person's performance decreases even when the frequency of information per source is held constant (Sanders and McCormick, 1987).

In order for a pilot to achieve a high level of performance, the number of sources of information needs to be kept to a minimum. When it is not kept to a minimum, pilots ignore or miss information through their selective attention process.

It is possible that the incorporation of the MIS could overload the amount of information presented in a cockpit and may decrease a pilot's performance. In order to avoid information overload, the MIS should have an adaptive display system where the number of sources of information being displayed at any one time will be limited according to the needs of that phase of a flight mission. As mentioned earlier under cognitive-psychology, the information density should be limited to

avoid information overload.

Adaptive Display Systems

An adaptive display system organizes information and allows the pilot to view the information on a limited number of screens. The information presented on each screen is specific to the present phases of flight. For instance, one display might have long range navigation information during level cruise flight. When the aircraft is at the site of interest, the display then has target or extraction information instead of navigation information.

Adaptive display systems are currently being researched for use in the next generation of military aircraft beginning with the YF-22. The YF-22 is undergoing experimental flight testing and may be in use within the next five years.

Given the large and variable information needs of the pilot, the MIS will utilize adaptive displays to provide relevant information to the pilot at appropriate times during a mission.

Summary

Military pilots have a basic understanding of the systems they use, but are not expected to be experts in each system. They rely on specific operation

limitations within which they operate the system. The MIS must therefore provide a restricted set of appropriate options to the pilot. The system will have the capability to provide 2D, 3D, static, and dynamic renditions of the map data, but information overload is a major concern for the cockpit environment. Consequently, the more complex 3D dynamic display will not be appropriate for in-cockpit use.

The cockpit MIS display must conform to established display frames of reference used in other flight instruments. The use of adaptive displays wherein the MIS shares physical displays with other systems is appropriate, although research is needed on the use of color CRTs for display color maps.

CHAPTER V

THEMATIC DATA NEEDS, DISPLAY TECHNOLOGY AND COMMUNICATION

This chapter presents specific aspects of the MIS design.

Thematic Data Needs

The following areas will play an important role in the development of soft-copy databases for use in Map Interaction Systems.

Terrain/Elevation Model Data

Terrain and elevation models provide the backbone of the MIS. These models approximate the terrain a pilot will see while flying. All other features, such as water, roads, and buildings, rest on this terrain model. The terrain may mask these other features, depending on the position of the pilot and his/her plane. Therefore, it is important to use effective terrain and elevation models.

A problem associated with the implementation of terrain and elevation models is that several different methods are used to create and store them. Currently,

the three most widely practiced methods involve a rectangular matrix (elevation, altitude, or surface matrix), a Triangulated Irregular Network (TIN), or a digitized string of contour lines (Carter 1988).

Digitized contours and TINs contain subjective information which reflects the bias of the operator who compiled the data. Regular matrices do not contain this subjectivity, unless derived from contour lines from a map, but areas of complex relief may not be as well represented since the algorithms in the computer program generalize the relief. A possible solution is standardizing the methods used. Acceptance of minimized deviations may improve regular matrices. At the same time, users should be aware of these limitations.

Another problem with digital terrain models is that as of yet, they do not yet cover the entire surface of the earth at sufficient resolution. This is a problem which the Defence Mapping Agency is working to overcome. Since the agency is shifting its focus and becoming an information management agency, it can accept responsibility for collecting and maintaining digital models.

Digital terrain models require removable thematic overlays. In terms of this thesis, overlays are simply classifications of similar data. The overlays need to be removable in order to allow the user the flexibility to

create customized maps or map displays.

Types Of Overlays

The primary purpose of the MIS is to verify a pilot's location and lead him/her to the mission target. Additionally, the MIS displays threat information. Thematic information needs are specific to these purposes.

Image overlays from remote sensors such as satellites can provide much of the same information as that of thematic overlays. Image overlays can be processed to highlight specific themes or features. They can also show information in both the visible and non-visible portions of the spectrum. However, the short-comings associated with images are that they only represent one moment in time, often contain distortions, and usually are limited to one or two scales. The information contained on an image is limited by the resolution of the particular satellite from which the data was gathered. Thematic overlays, on the other hand, can be updated quickly. They can be used in association with animation to create future or expected scenes. Additionally, a thematic overlay can also be removed from a scene to observe the environment without a certain feature present. Finally, remote sensing image data may create problems with information overload

or clutter, as described in the previous chapter, and are not recommended for in-flight MIS use.

Perhaps the most important overlay in an air navigation system is water. Rivers, streams, and lakes are some of the easiest features to identify from the air. Even when water bodies are intermittent, surrounding features provide clues to the relative location of where a body of water is located. For example, vegetation and animal paths are commonly found adjacent to water features. Water features may vary in level at different times of the year, however current maps show water features at a constant level. In the future, updated MIS's may depict levels of water features based on the time of year.

In addition to water, roads are also prominent terrain features. Roads are good navigation tools when they are available because they usually lead to distinctive points which pilots individually select to help them navigate. And since roads are constructed by humans, they tend to be linear features unlike anything found in nature. Roads can be difficult to identify, however, because military activity can destroy them beyond recognition. It is also possible that a road is covered with tall vegetation. Furthermore, dirt roads are difficult to identify from the air because they are made from the same materials as the surrounding

environment.

Another overlay which may be of significance is powerlines. Powerline overlays may be included with road overlays. Powerlines usually require the clearing of large linear areas of vegetation. The problems with using powerline overlays for navigation is that aside from the towers, it is difficult to see the lines from the air. Furthermore, energy sources such as powerlines are usually targeted at the beginning of any crisis and may not be present later in a military conflict.

Buildings can be useful features for navigation, but they can not always be relied upon. Relatively speaking, it does not take long to construct a building, but it takes even less time to destroy one. During a crisis situation, buildings tend to be destroyed at a very rapid rate. For this reason, building overlays should be made available in the MIS but their limited application should be recognized.

Buildings can be categorized into military, government, industrial, or residential. It may be important to categorize buildings in this manner and to classify them as separate overlays. As a military crisis evolves, certain buildings such as military buildings are often destroyed before others. If a building category such as "military buildings" was not located on separate overlay, absence of the buildings

could be a distraction to the pilot. The pilot may want to use a building for navigational reference and it may no longer be present.

Absolute location is very important in air navigation. Latitude and longitude are often the first methods used to identify a feature or location. For this reason, a GPS grid overlay might be a very helpful part of the MIS. By having such an overlay, the pilot could confirm redundant information with other instruments. This confirmation could reinforce the pilot's targeting decision and minimize unnecessary mistakes.

Available Technology

With the rapid advancement of computer technology, many products are already available which could be applied to the development of the MIS. This section will examine several products which may contribute to the development of the MIS. Presentation of this material will show how the MIS will be different from current systems.

Published Cockpit Resource Literature

Rapid advancements in navigation technology have already provided material and hardware which can be used to support a Map Interaction System. New computer

technology is operating faster than ever and is currently being integrated into military navigation systems. Satellites are being used to link ground soldiers with base units in a matter of seconds. Memory devices which utilize iconic (icons) storage are replacing cumbersome keyboard interactions. These current innovations in technology can be combined to meet the desired capabilities of the MIS.

One of the desired capabilities of the MIS is to visually display static and dynamic maps at the pilot's request. Several possible solutions could be implemented to meet this demand. One solution to this challenge is to simply utilize tools already available in the cockpit. If an adaptive display system is already available in the aircraft, then it makes sense to utilize one of those displays to display information from the MIS. The pilot would already be accustomed to the layout of the cockpit environment. For example, MIS information could be displayed on an established multipurpose screen when weapon status information is not. Information from two systems, the MIS and/or a weapon status system could be displayed at the pilot's discretion.

Not all cockpits have adaptive display systems. Flat panel displays could be the multipurpose screens used in cockpits lacking an adaptive display system. It

would be convenient to implement these along with the MIS. Commercial flat display screens are currently being investigated by the military.

> Flat panel displays are thin, lightweight screens that display numbers, letters and pictures in electronic products from laptop computers to automobile dashboards to analog wristwatches and fever thermometers (Matthews 1994:39).

The Department of Defense (DOD) plans to begin purchasing flat panel displays starting in 1995. According to the Air Force Times, DOD will use them in planes, tanks, ships, and by individual service members (Matthews 1994). It is not known whether this type of display has been tested in a cockpit environment.

The U.S. Army is currently using hand-held navigational computers with six-inch video screens for scouting purposes. A scout is capable of viewing an area map, marking a target on the map, generating GPS coordinates, and sending the information back to his/her unit. "The Army plans to have at least part of an armored brigade fully computerized by 1996" (Matthews 1994:32).

The idea of placing maps and other information on the visor of a pilot's helmet has been considered. It is not known how much research the DOD has conducted in developing this technology but advancements have been made in the private sector. A company by the name of TigerSoftware has a product which allows a person to

watch television programs on the lens of his/her sunglasses.

Visor displays may not be an effective means of navigational communication since they demand that the pilot fixate on the visor and then refocus on the surrounding environment (the instrument panel or the environment outside the windscreen). Visor displays would force a pilot to fixate and focus on three separate environments. The MIS requires fast on-board data processing and management, requiring advanced computer technology. In order to hold and process all of the data necessary to operate the MIS, both computer memory and speed will have to be improved. However, computer technology is advancing at a rapid rate and it may already be adequate for an on-board MIS.

> Companies will have to scramble to keep up as computer processing speed doubles every 12-18 months, software operating systems go through revolutionary changes and vendors that sell computer-aided-design tools reinvent their entire product lines (Hughes 1993:105).

Computers may already be capable of handling new ground-based mapping systems. Currently, 43 Air Force Reserve Intelligence units throughout the country are equipped with this new mapping system. The system has a worldwide data base consisting of military forces and buildings. Operators can implant sites directly onto maps and print them in color. Photographs can also be displayed and printed on this system (Compart, 1994).

Computers are also taking an important role in linking information systems with pilots. Timely communication is vitally important in a crisis situation. In order to make life-threatening decisions, pilots rely on timely communication. In the past, ground/pilot communication has been restricted during actual flight since the only means to do so was by voice. Voice communication can be intercepted and used to pinpoint an aircraft. Computer communication is replacing voice communication because it does not jeopardize a pilot's position and it can easily be coded.

New computer and communications systems are currently being tested by the U.S. Air Force that will be capable of delivering information from satellites, control aircraft, and sensors, directly to the cockpit. The information these systems will transmit to the cockpit will include incoming threats, weather changes, and mission updates. The information will be displayed on existing cockpit displays (Hudson, 1993).

Researchers and designers are including a new system in the next generation of fighter aircraft. The F-22 will be equipped with an interflight data link system that will allow an F-22 pilot to coordinate tactics with at least three other aircraft (Morrocco, 1993). Information received by one aircraft can also be

received by any other. This interflight data link system is not yet fully developed and it may be a more powerful tool once all of its capabilities have been realized. The concept of linking aircraft and the linkage system will play an important role in the MIS.

The last technological advancement to be discussed is the expanded use of iconic storage. Many modern computers are designed with touch screens. Touch screens eliminate the need for cumbersome and oversized keyboards. Touch screens utilize icons for managing and organizing information. Not all information can be represented by icons, and programs which use keyboards have a comparative advantage in the amount of information which can be presented. Icons provide an alternate means of human-computer interaction that may keep systems simpler and more user-friendly. Touch screens with icons take up less space than displays with keyboards. If the MIS is to be implemented into the cockpit, it will have to be small and simple to use. Touch screens may not be practical for implementation in the cockpit because of size and vibration, but icons may be the answer to a simple and fast MIS, especially because the system will use limited adaptive screens and the pilot's options will be restricted.

Differences Between The MIS And Virtual Reality, GIS, And Radar

How will the MIS be different from currently available display technology such as Virtual Reality (VR), Geographic Information Systems, Global Positioning Systems, or Radar Systems? Virtual Reality allows the user to view the environment from many different perspectives. The MIS would also provide the pilot with varied perspectives. However, the MIS would also allow the pilot to alter navigational scenes by adding information which could also be sent to other users. For instance, if the pilot noticed an enemy threat along the path of flight, he/she could update that scene and send it as a warning to other pilots or to the base unit.

The MIS would be similar to a GIS in that digital maps would be utilized as well as several valuable functions. Functions which enable the pilot to determine the path of least resistance through enemy threats, or attribute information about each threat, could be utilized in the MIS. Exactly which functions would be incorporated into the MIS would depend on those developing the systems.

Global Positioning Systems are locational systems which would be part of the MIS. Global Positioning MIS's would be used to give accurate locations of

objects, threats, and the plane itself.

Radar systems are used to provide detailed images of environments below an aircraft. Radar images are usually available from only one vantage point and are only effective while flying. Radar images are not called up for reference in advance of the flying mission, and are not manipulated with codes and overlays and sent to other agencies. The reason being is that a supporting database and system have not been established for these purposes. The MIS would allow the pilot to use any image or scene upon request. This will be possible because of the implementation process (discussed later) which will establish a fully functional MIS.

The ideal MIS would utilize the best aspects of all the systems mentioned above. The MIS would be an interactive digital map system which simulates the environment the pilot will, or already has passed through. Overlays such as terrain, water, roads, buildings, and powerlines would be incorporated with digital maps. The pilot would be able to add or remove overlays at his/her discretion.

There are several weapons used today which are able to independently pinpoint targets. Some weapons use video, lasers, or radar. These weapons are, however, very expensive and, as a result, they are in short

supply. The large majority of weapons used today are referred to as "dumb bombs". The accuracy of these weapons depends on the skill of the pilot, or weapons system operator, delivering the weapon. For this reason it is important to provide the pilot with a navigation system which can assist in finding and confirming a location that is targeted. The MIS could be used by pilots to facilitate target acquisition.

The navigation system is not only intended to be used with weapons. It could be extremely helpful for search and rescue mission or for accurate delivery of supplies.

Integration And Communication

Effective communication is important in every crisis. In order to effectively handle a crisis, information must be rapidly transmitted and understood. This section asks the question: "who should be able to communicate using a Map Interaction System". How the communication process will take place will be discussed as well as the advantages and disadvantages of using the MIS to communicate.

Among Whom?

Effective decision making occurs when there is an overall understanding of a situation. The vantage point

and perspective of the pilot, if transmitted quickly, can help provide decision-makers with alternate and up-to-date information concerning military situations. The timely manner in which decision-makers receive information may be the difference between life and death of those involved. For these reasons, it is important that a Map Interaction System be designed with the capability to receive and transmit information between the aircraft and other agencies.

An effective MIS will allow the pilot to communicate with other aircraft as well as with several different agencies. Interflight communication can be very valuable. When aircraft travel in formation, the lead aircraft is responsible for all others. It is the responsibility of the lead aircraft to coordinate the actions of the entire formation. Coordination during flight is usually accomplished using hand signals. Radio communication is minimized to prevent detection by the enemy. Interflight data linkage would allow a formation to communicate more effectively than through simple hand signals.

Important communication linkages exist between the pilot and the Airborne Warning And Communication System (AWACS). AWACS is installed on Boeing E-3A Sentry aircraft. AWACS is responsible for the surveillance of all air vehicles within an area of possible detection.

Information from AWACS aircraft could be communicated more effectively to other aircraft through the MIS. It would also be helpful if the MIS could send information to the AWACS, and onto other aircraft in the area.

When mission plans change after an aircraft has been launched, a base unit could communicate updated information to the pilot through the MIS. Similarly, an airborne pilot may warn other pilots of changing conditions before they take-off. Communication between a base unit and an aircraft through the MIS could benefit both agencies.

How? (Theoretically)

How can this communication be accomplished? Communications can be accomplished using current technology. As explained earlier, interflight data linkages are currently being developed for use in the next generation of fighter aircraft. Soldiers are using computers in the field and transmitting information back to their base unit via satellites. It is clear that current technology should allow for the MIS to be linked with the agencies mentioned above, such as AWACS units or bases.

How are pilots going to interact with the MIS? Pilots are already tasked with flying and operating aircraft systems. There are a number of ways in which

pilots will be able to operate the MIS.

The Map Interaction System can be developed in different ways which utilize different techniques. Thus far, several ideas have been proposed regarding how the MIS might be implemented. Some of these proposed MIS's are better than others. A monitor display is perhaps the simplest way to implement the MIS because it would not interfere with the pilot's view. Virtual reality developments may be worthwhile for simulation, but the information displayed may be distracting to the pilot while in flight. The displayed content should incorporate the principles mentioned earlier: consistency of reference frames, effective colorization, and minimized clutter. It is possible to place a MIS display in many locations within the cockpit. It is important to remember that the MIS display should be easy to interact with, yet it should not interfere with the pilot's primary mission. For these reasons, it might be best to place the MIS display off to the side (but not far from the front) of the pilot's view. The system could also be integrated with other display systems such as weapon system displays. When one display is not in use, the other could be displayed. Using an Adaptive Display System may be the best way to implement the MIS.

Another area that may provide safe and effective

viewing of map information is the windscreen itself. As with the automobile, it is important for the pilot to keep his/her view out the cockpit as much as possible. This is primarily for safety reasons. If maps were displayed on the windscreen without obstructing the pilot's outside view, then the pilot could use the redundant information to support his/her decision and pinpoint the area of interest. This form of display may provide a more realistic view of the environment than a flat map display.

Just as there are many ways to display navigational information, there are many ways for the interactions between the pilots and the computer to take place. The pilot could control image displays using voice activated commands just as commercial phone systems that recognize user voices to activate certain basic commands. Current voice recognition systems are problematic because there is a limited number of voice commands, the speed of talking may be too fast for accurate recognition, the separation of words may be difficult to differentiate, and the systems usually have to be "trained" for each individual user. Voice recognition systems may also be difficult to utilize because other cockpit voice communications may interfere with the system.

The pilot could use a joystick or a "mouse" to interact with the MIS computer. Using a touch screen is

also a possible means of interaction. Both of these techniques would be difficult to use because of vibrations during flight and the size of a pilot's hands relative to the size of the display. A combination of these techniques may prove possible.

Perhaps the best method of human to computer interaction is through the use of laser technology. An infrared laser could be the light source and act as a pointing device. A video camera could pick up the corneal reflection of the pilot. With this technology it is possible to precisely perform the necessary interactions. This technology is already being used with disabled people who have difficulty communicating. The video camera follows the eye movement and communicates the words or letters being looked at by the user (Schlegel, 1994).

A "button" or confirmation device would have to accompany a laser device. Voice communication, eye blinking, a foot operated button, or a trigger in a pilot's glove could be used for this purpose.

If laser technology were to be used, a pilot could simply look at icons and move or drag them around the display to develop data or an image. Laser technology would provide a quick and simple means of interaction that could take place without interfering with the pilot's basic aircraft control.

As has been mentioned, an important objective of the MIS system is that it must be simple to operate. Therefore, icons will need to be simple in design, distinctive, and easy to recognize. This may be accomplished by using visual techniques such as outlining and shadowing. To keep the MIS simple, the number of icons being displayed should be minimized. In order to keep the number of icons to a minimum, several important icons could have an 'expansion' feature. For instance, when the pilot desires to send data or an image to another agency, he/she will select a "send" icon which will expand, asking to which agency the data layer should be sent. The pilot will be able to send the data or image to a ground agency, an airborne command center, and/or other members of the formation.

There are several possible ways to implement the ideas discussed in this paper. The Map Interaction System is not limited to the approaches mentioned here. This thesis is designed to present the possible needs for future spatial displays and guide researchers interested in this area of design.

Advantages/Disadvantages

Using the MIS to communicate information will be advantageous for several reasons. First of all, coding digital information is easier to do than coding voice

communication. Voice coding involves scrambling or alternating frequencies. If voice communication is intercepted, the information can be immediately understood and used. Digital coding can be changed simply by assigning different values to digits. If digital coding is intercepted, its message will not be immediately understood and information cannot be used right away.

The Map Interaction System will be utilized by many different users. The primary users will be pilots. Base support units will be heavily involved in maintaining, sending, and receiving map information. Most MIS users will be involved in customizing visual maps and yet these users will not have been trained as cartographers. Lack of cartographic training by MIS users could cause MIS problems such as using source data at an inappropriate scale. For this reason, standardization and automation should be established by cartographers and system designers only. They can give displays a limited range of options.

The Defense Mapping Agency provides the source of digital mapping data and the DMA should be the agency responsible for establishing the majority of structural standardization of the data. Cartographers involved with animated cartography provide perhaps the best pool of knowledge to automate and limit the ability of a user

to customize a visual map.

Summary

The thematic content of the MIS display will be based on digital terrain models overlain with selected overlays whose primary purpose is to help the pilot determine absolute and relative location. Interflight data linkages are just now being established on an experimental basis in aircraft but offer major capability/functionalism for a fully developed MIS. However, communication is a secondary function of the MIS, the primary function will remain as navigation. The MIS incorporates many capabilities with virtual reality, radar, and GIS, but will implement them specific to cockpit needs. There are many viable options for the in-cockpit display and the pilot's interaction with it.

CHAPTER VI

FLIGHT PHASES AND IMPLEMENTATION

Phases of Flight

Flying missions begin long before the plane leaves the ground and continue even after the plane returns. Pilots are not simply airplane drivers. Their responsibilities extend beyond the extent of flight. Pilots must prepare for a mission, fly the mission, and then explain the events which took place during the mission. Pilots rely on maps and map information throughout the mission. The MIS proposed in this thesis will be a flexible adaptive system that can provide an appropriate combination of system options for each phase of a mission, e.g. data format (hard-copy vs. soft-copy), thematic information content, display rendition (2D vs. 3D, static vs. dynamic), display type, and method of pilot/MIS interaction.

This chapter partitions the mission into five distinct flight phases, each with particular information needs and appropriate display technologies and techniques. These phases are: pre-flight planning, en route, mission execution, return route, and debriefing (refer to Figure 6.1).

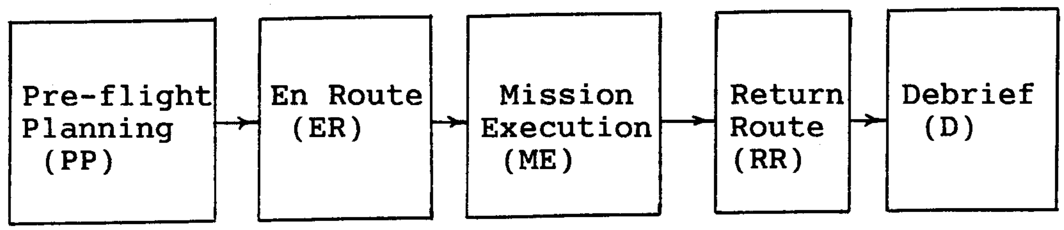

Figure 6.1 Phases Of Flight.

Powerful techniques for advanced 2D and 3D map displays are not needed during all phases of flight. As mentioned earlier, they may not be appropriate at all times. Based on the previous discussion and the experience as a pilot, Figure 6.2 was constructed to show when each type of map may be effective. The three headings refer to the stages of implementation for a fully functional MIS (discussed in the next chapter). The GIS updating stage will allow pilots to use a GIS database mapping system while preparing and debriefing a mission. The next stage involves a non-interactive system, where soft-copy maps will be used in the cockpit during a mission. The last stage will be the complete MIS.

The types of maps that will be used are 2D and 3D static maps, which represent one moment in time, and 2D and 3D dynamic maps which show changing information over time.

GIS Updating

	PP	ER	ME	RR	D
2D Static	X				X
3D Static	X				X
2D Dynam					
3D Dynam					

Non-Interactive System

	PP	ER	ME	RR	D
2D Static	X	X	X		X
3D Static	X	X	X		X
2D Dynam		X	X	X	
3D Dynam	X				X

MIS

	PP	ER	ME	RR	D
2D Static	X	X	X	X	X
3D Static	X	X	X	X	X
2D Dynam		X	X	X	X
3D Dynam	X				X

Figure 6.2 Soft-Copy Maps For Phases Of Flight.

In the following sections, for each phase of flight, the functions, techniques, design considerations, and user needs of a Map Interaction System are discussed next:

Pre-flight Planning

Pre-flight planning is essential to any successful mission because it can enhance the pilot's situational awareness during unexpected or emergency situations. An unexpected or emergency situation during flight can be broken up into three stages. The pilot must recognize that an improper situation is taking place. Second, the pilot must analyze and process all information that he/she can gather that pertains to the situation. And third, the pilot must react and take proper action to correct the situation. This must all take place while maintaining basic aircraft control. Simply put, situational awareness is analogous to having a bird's eye view of one's surroundings. Situational awareness requires an understanding of spatial relations among elements in the surrounding environment. Situational awareness is enhanced through familiarization with the route of travel and the area of interest. Together, situational awareness and preparation can minimize the time it takes for the pilot to analyze and process the necessary information required for proper decision

making. The more prepared the pilot is, the more time he/she will have to deal with the unexpected and hazardous occurrences during the actual flight.

During pre-flight planning, the pilot visualizes how he/she expects to conduct ensuing tasks. Presently, the pilot must imagine how the mission will unfold with the help of paper maps. The paper maps are out of date and must be corrected manually using a current listing of recent additions such as new towers. In the future, the complete MIS will utilize a base computer which will consist of computerized temporal maps and animation, created by Geographical Information Systems. These computerized temporal maps will have data and visual scenes which will change with time. The pre-flight planning phase will make the most extensive use of 2D and 3D static and dynamic displays that will allow the pilot to conduct numerous simulations of the mission, varying flight parameters for each simulation.

Computerized temporal maps and animation (mentioned earlier) will be vital tools in accomplishing more accurate pre-flight planning. Commanders will be able to brief aircrews on missions using two-dimensional and three-dimensional simulations. Individual pilots will be able to plan and become familiar with their specific routes and the surrounding areas.

Since no two situations are alike, the MIS being

used must allow for flexibility. Aircraft can take on different missions at different times. For example, the General Dynamics F-16 Fighting Falcon is capable of performing missions at both high altitude and low altitude. In order to meet these different situations, the MIS must be flexible enough to provide several possible perspectives of a route. During pre-flight planning, the pilot should be able to select specific perspectives suitable for each stage of the mission. For example, the pilot may select to view the target zone with a 3D perspective at an altitude of 500 feet. Once a perspective is selected, the pilot will then be able to visualize the route and its surrounding area. This is what pilots often refer to as "chair flying". It is similar to a downhill ski racer visualizing the turns of the course before the actual race begins. The pilot could be shown the direction of the prevailing winds, how much fuel he/she should have at certain points along the flight path, and the nearest emergency airfield at points along the flight path.

The pilot will be able to customize the route for his/her personal performance. He/She will be able to use the Map Interaction System to display items which will serve as reminders along the flight path. The system will have to be flexible to match an individual's needs. For instance, the pilot may choose to incorporate

a reminder flag at a certain stage of the flight to remind him/her that the load being delivered is ready to be dropped. Or a flag may be placed along the flight path to look for evidence of trouble in the area or for potential threats.

Following pre-flight planning, the pilot will carry individually designed MIS route information to the cockpit and will install it into a compatible cockpit system just as a writer might transfer soft-copy information from one computer terminal to another. Computers utilized in the planning room, need to be closely related and compatible to those located in the aircraft.

En Route

Most of the constraints which must be considered when designing a Map Interaction System stem from this phase of flight. The pilot is tasked with many other high priority demands during this stage. If the MIS is not designed carefully with this phase of flight in mind, then the system will be useless to the pilot and to those depending upon the information that it might provide.

Once the pilot has leveled off at the cruising altitude, he/she can then turn part of his/her attention to the MIS. The pilot will be afforded the opportunity

to view scenes of previous, current, or future interests. During this time the pilot will also have access to a 2D dynamic map display which will allow him/her to reference the aircraft's present position.

The pilot will be able to interact with a scene of choice and update any MIS information he/she may feel is pertinent. The pilot may see threats or areas of high interest along the route that he/she may want to relay to other agencies using interflight linkages and/or satellite communication.

The MIS will allow the pilot to select icons and to quickly develop a visual scene or image that can be transmitted to another agency or be saved for later debriefing. This newly developed data layer will automatically incorporate time, position, name of the aircraft, and the vector to an object on the ground. This can be accomplished using the Global Positioning System (GPS). Time, position, and 3D direction of the aircraft during the creation of the data layer is vital information to those receiving the data as there may always be more recent data available. Other aircraft, in a more advantageous position, may have a more accurate assessment.

The MIS will also allow the pilot to receive data from other agencies which might be important to his/her mission. The receiving function will have to be an

optional selection for the pilot. The pilot will be informed that there are potentially applicable data or images available. The pilot will be able to view a set of the available data or images in a table or map. This list will only have data layers that are within a certain distance of the pilot's route. The computer will be programmed to sort through the available data and images and show the pilot only those themes pertaining to his/her route of flight. The pilot will be presented with the time, position, and developing agency of the available data.

Mission Execution

When the pilot is approaching the target zone, the MIS can then be called upon to guide a pilot through that area or to display the scene which the pilot created as a reminder during the pre-flight planning phase. Regardless of the display, the MIS will only serve as a display during this time. There will be no interaction between the pilot and the system since the pilot will be concerned with the primary purpose of the mission at this time.

The pilot will be allowed to use the MIS for positional reference by continuing to display a 2D dynamic map. During this time it is likely that the pilot will ignore or turn off the MIS.

Return Route

Once the main objective has been met and the pilot is safely returning to base, the interaction between the pilot and the system can be most useful. The hostile areas or simply areas of interest are completely fresh in the mind of the pilot. This vital information can be transmitted in an accurate and timely fashion to other interested agencies. The pilot can give more attention to developing a worthwhile image or data during the return portion of the mission. The pilot will be able to partially debrief his commander and others before he/she even returns. In turn, the commander can make timely decisions.

During the return route, the pilot will be able to communicate once again using satellite communication and/or interflight linkage. The pilot will be able to work with 2D or 3D static images for communication purposes. The pilot will need the flexibility to communicate several different types of threats. Designers must limit the flexibility and variety to some extent for the sake of the receiving agencies. If the pilot is allowed too much flexibility, then a receiving agency may not be able to interpret the highly personalized image quickly enough to use the information. There must be some commonality designed into the system.

The MIS will continue to allow the pilot to navigate using 2D and 3D dynamic maps if he/she chooses. The pilot can use these maps once again for positional references and navigation.

Debriefing

The Map Interaction System will be helpful to everyone involved in the debriefing, but it may be especially helpful to the pilot. It will help the pilot remember each phase of flight. It is easy for the pilot to confuse different portions of a long flight since so much action and information are being managed during a mission.

The MIS will allow the pilot to visually indicate where and what problems were encountered along the route. The pilot will be able to use each type of map, 2D, 3D, static or dynamic. Animation will help the pilot to explain similar circumstances to what he/she encountered or what others might encounter.

Stages Of Implementation

The current cockpit map environment is based on using published hard-copy aeronautical charts. The MIS environment presented here is an interactive adaptive soft-copy environment that is fundamentally different. The transition from the former to the latter will be a

gradual process that takes place over an extended period of time, probably 10-15 years. Each stage of the process will help developers recognize problems and overcome difficulties, and will be a building block on which to base a fully functional MIS.

Given that the transition to a fully-functional MIS will take time, it is necessary to ensure that the intermediate stages of the process provide useful functionality to the pilot. The overall development of the MIS has been broken into four stages (refer to Figure 6.3).

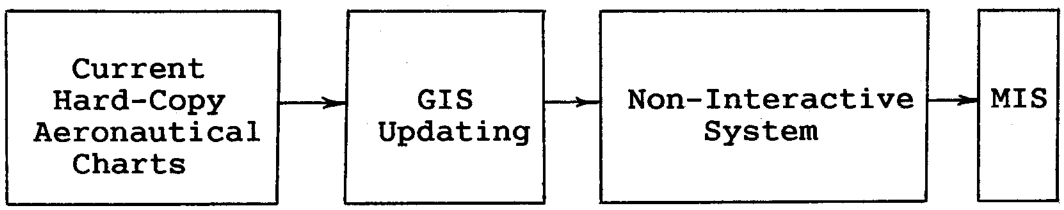

Figure 6.3 Stages Of Implementation.

Each stage will have several functions and provide advantages over the previous stage(s). Figure 6.2 depicts which type of soft-copy map should be available for each phase of flight throughout the phases.

The first stage describes how maps are currently used. Hard-copy paper maps are manually updated and hand-held in the cockpit. Low-level maps are often cut and pasted together for a specific use. The only advantage to this current approach is that pilots are

already accustomed to using maps in this way.

The second stage of implementation (GIS Updating) will be to change to a soft-copy database. It may be possible to change to a structure used in current Vehicle Navigation Systems. The soft-copy database will have current aeronautical charts and maps at several scales. Each map will be up-to-date and continuous. The user will be able to define the limits of the desired area.

This stage will also have a program to compute expected headings, timing, fuel consumption, and emergency airfields based on aircraft type and pilot-selected ground points. In other words, there will be a program to create low-level maps based on selected ground points (this capability is available already for civilian aviation).

From the soft-copy database, pilots will create hard-copy products to be used in the cockpit during flight based on their needs. This stage is in line with the Defense Mapping Agency's new focus. The DMA is the provider of aeronautical charts to the military. Based on the survey, this stage will be a vast improvement. Potentially, all military pilots can benefit from this stage.

This stage will bring about several new advantages. First of all, it can be accomplished relatively quickly.

Commercial GIS systems are already available on the market. It will also save pilots time. Pilots will no longer have to search through books to update maps. They will not have to cut and paste maps just to cover their selective area. Timing, fuel consumption, and headings will automatically be calculated for pilots. This stage will also save paper. One sheet of paper will be used rather than two or three sectional maps. There will be one hard-copy product of the area unless it is too large and requires more.

The next step towards a complete MIS is to develop a Non-Interactive soft-copy System. During this stage, animation and visualization will be added to the soft-copy database. Animation and visualization will help prepare the pilot for the actual route of flight. This will help the pilot to accurately execute the mission.

Digital maps will be added to the cockpit during this stage. Pilots will be able to view digital maps on a moving-map display. The display will show the pilot's current position on the map. The hard-copy maps will only be carried for emergency purposes.

This stage will have several advantages. The pilot will be able to improve his/her preparation for the mission. This preparation and improved accuracy of the maps will help the pilot to be certain of the target. Also, with the reduced use of hard-copy products,

organization within the cockpit will improve. This will make a better work environment for the pilot.

The final stage will involve implementing a fully functional MIS as described earlier. The pilot will interact directly with the system while in flight. Communication with other pilots and other agencies will also take place. The system will incorporate all the functions described in the earlier stages as well. The advantages during this stage will be increased pilot preparation, improved communication, and reduced navigation and targeting mistakes.

CHAPTER VII

RECOMMENDED RESEARCH AND CONCLUSIONS

In order for a Map Interaction System to become operational, certain developments and experiments may be necessary. First of all, animated and virtual reality scenes must be further developed, especially those involving three dimensions. The three-dimensional images will take some time to create effectively. Currently, two-dimensional images and animated scenes are being produced effectively even if they are not extremely detailed. Detail and improvements will come with time.

One area that needs further research and experimentation is cognitive psychology. Experiments in this area could inform the developer and other cartographers of the information density that can be contained on a map of a particular size in the unique high-stress demands of the cockpit environment.

Interaction devices between the pilot and the computer need to be researched. It will be necessary to experiment with the ability of the pilot to use the interactive devices effectively during many situations such as day and night operation as well as poor weather

operation.

Certain areas, such as building the database, may slow the development of the MIS. The rate of advancement of these areas will largely depend on the advancement of technology. The current computer processing speed is too slow to process the necessary amount of data to create an effective display image.

This study started with the preconception that a fully functional MIS was the immediate goal. After research began, it became apparent that there is a shift occurring from hard-copy and soft-copy maps. However, until technology advances further, hard-copy maps will remain dominant in the cockpit. Major gains can immediately be made involving these hard-copy maps. The time-consuming task of updating maps can be accomplished using GIS systems already available to commercial aviation. Best of all, pilots will not have to learn a new system and aircraft will not have to be equipped with new hardware right away.

At the start of this research, it was not anticipated that a pilot should have limited access to the types of maps available. However, 2D, 3D, static, and dynamic maps are not relevant for all phases of a mission. They should not be available for a pilot to decide when to use because of a pilot's lack of time to decide and lack of experience with cartography. Two-

dimensional dynamic maps are less effective during pre-flight planning, as a pilot can not afford to watch an entire mission. Portions of a mission require more of a pilot's attention than others. For example the final approach to a target needs to be studied more so than a portion of the return route. Therefore, other types of maps, such as 3D dynamic maps, should be referred to more closely than the 2D dynamic maps.

The 3D dynamic maps will show information in a real time sequence. These simulated perspectives can help the pilot prepare for a mission, as well as debrief it. During flight the pilot must divide his/her attention among several tasks. For this reason, 3D dynamic maps are inappropriate during flight. These maps would be disorienting to a pilot since a different perspective would be shown from the one the pilot is actually experiencing. Other tasks, such as preparing weapon systems and avoiding threats, are important during flight. Pilots must prepare for navigation before flight.

The stages of implementation were not considered at first. With the realization that current hard-copy maps are primitive, the need for stages of implementation developed. Each stage can involve major developments that will contribute to an effective MIS. A fully developed MIS will require a large database and an

interconnective computer system. With the aid of GIS and a database system, current hard-copy maps can be updated rapidly and relieve pilots of this task. This database can be the foundation of the MIS and quickly improve the quality of the maps currently used. The stages of implementation will help to continually improve and update maps until a fully developed MIS is achieved.

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